SUBCOMMITTEE ON SPACE AND AERONAUTICS
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

HEARING CHARTER

Discovery on the Frontiers of Space: Exploring NASA's Science Mission

Tuesday, June 11, 2019
10:00 a.m.
2318 Rayburn House Office Building

PURPOSE

The purpose of the hearing is to review the National Aeronautics and Space Administration's activities and plans for its Earth and space science programs, including the Earth Science, Planetary Science, Astrophysics, and Heliophysics divisions of the Science Mission Directorate, and associated issues.

WITNESSES

- **Dr. Thomas H. Zurbuchen,** Associate Administrator, Science Mission Directorate, National Aeronautics and Space Administration
- **Dr. Chelle Gentemann,** Senior Scientist, Earth and Space Research; Co-chair, Committee on Earth Science and Applications from Space, Space Studies Board, National Academies of Sciences, Engineering, and Medicine
- **Dr. David Spergel,** Charles A. Young Professor of Astronomy, Princeton University; Director, Center for Computational Astrophysics at the Flatiron Institute; Former Chair, Space Studies Board, National Academies of Sciences, Engineering, and Medicine
- **Dr. Mark Sykes,** Chief Executive Officer and Director, Planetary Science Institute

OVERARCHING QUESTIONS

- *What are the emerging science questions in astrophysics, planetary science, heliophysics, and Earth science, and what, if any, developments are key to enabling progress in answering them?*
- *What is the status of NASA's implementation of the priorities put forth by the scientific community through the National Academies' decadal surveys?*
- *What are the most significant challenges and opportunities for the future of space and Earth science research?*
- *What is the status of NASA's science research grants program and what needs to be done to ensure its continued productivity?*

- *What questions and issues need to be considered regarding the relationships among science, human exploration, and commercial space activities?*

BACKGROUND

Scientific research has been part of the NASA mission since the agency's founding. The National Aeronautics and Space Act of 1958 includes among the eight objectives of the nation's aeronautical and space activities: "The expansion of human knowledge of phenomena in the atmosphere and space."[1] The NASA Transition Act of 2017 amended the list to include another science-related objective: "The search for life's origin, evolution, distribution, and future in the universe."[2] NASA's Science Mission Directorate (SMD) is the primary home of NASA's science efforts, although programs in the Human Exploration and Operations Mission Directorate (including the Division of Space Life and Physical Science Research and Applications) and the Space Technology Mission Directorate involve science-related activities. NASA's SMD comprises four scientific divisions:

- Earth Science, which seeks to advance knowledge of Earth as a system to meet the challenges of environmental change and to improve life on our planet.
- Planetary Science, which seeks to ascertain the content, origin, and evolution of the Solar System and potential for life elsewhere.
- Astrophysics, which seeks to discover how the Universe works, explore how it began and evolved, and search for life on planets around other stars.
- Heliophysics, which seeks to understand the Sun and its interactions with Earth, the Solar system, and the interstellar medium, including space weather.

NASA's Science Mission Directorate as Proposed in the FY 2020 NASA Budget Request

The NASA Fiscal Year (FY) 2020 budget request for SMD, as detailed in the table below,[3] proposes a total of $6.3 billion, a 9% cut from the FY 2019 enacted appropriation. In addition to the budget lines for the four divisions listed above, the James Webb Space Telescope (JWST), an astrophysics mission in development, is book-kept in a separate budget line within SMD.

Budget Authority (in $ millions)	Actual FY 2018	Enacted FY 2019	Request FY 2020	FY 2021	FY 2022	FY 2023	FY 2024
Earth Science	1921.0	--	**1779.8**	1785.6	1779.7	1666.5	1674.6
Planetary Science	2217.9	--	**2622.1**	2577.3	2629.4	2402.4	2350.9
Astrophysics	850.4	--	**844.8**	902.4	965.2	913.5	907.7
James Webb Space Telescope	533.7	375.1	**352.6**	415.1	175.4	172.0	172.0
Heliophysics	688.5	--	**704.5**	638.6	769.3	692.0	709.8
Total Budget	**6211.5**	**6905.7**	6303.7	**6319.0**	**6319.0**	**5846.5**	**5815.0**
Change from FY 2019			**-602.0**				
Percentage change from FY 2019			**-8.7%**				

[1] U. S. Code 51.20102(d)(1)
[2] U. S. Code 51.20102(d)(10)
[3] Table from page SCMD-4, NASA FY2020 Budget Request, Congressional Justification

The four science divisions manage diverse portfolios of research, missions, and technology development. Competitively-selected grants in research and analysis support approximately 10,000 (in 2018) students, postdoctoral fellows, and scientists both at NASA centers and at institutions around the country.[4] SMD operates a fleet of more than 80 spacecraft from low Earth orbit (LEO) to beyond the edge of the Solar System that is a mix of small, medium, and large ("flagship") missions, including competitively-selected principal investigator-led (PI) missions and NASA-led large-scale, "flagship" missions. High-altitude balloons, sounding rockets, and CubeSats and small satellites additionally support science, technology demonstrations, and student projects under SMD. In addition, across the divisions, SMD invests in early-stage technology development to enable potential future missions and SMD's Science Activation program supports competitively-selected teams to connect NASA science experts and content to learners. As stated in the FY 2020 Congressional Budget Justification document, NASA "*uses the recommendations of the National Academies' decadal surveys as an important input in planning and prioritizing the future of its science programs."*

NASA Programs and the National Academies of Sciences, Engineering, and Medicine's Decadal Surveys

NASA contracts with the National Academies of Sciences, Engineering, and Medicine[5] to carry out "decadal surveys," community consensus reports that prioritize the most compelling science questions for the next decade and recommend a program to best address them and optimize scientific return on federal investment.[6] The National Academies published the first decadal survey in astronomy in 1964[7] and has published a new survey approximately every ten years since. The National Academies went on to issue the first decadal surveys in planetary science and solar and space physics in 2003 and Earth science in 2007.[8] NASA is the primary sponsor of these decadal surveys; however, other relevant federal agencies, such as the National Science Foundation (NSF), Department of Energy (DOE), National Oceanic and Atmospheric Administration (NOAA), and U.S. Geological Survey (USGS), may be co-sponsors. NASA is required[9] to take into account the decadal surveys when submitting the President's annual budget request to Congress. Decadal surveys and mid-decade assessments ("midterms") in the four disciplines are now carried out regularly on a staggered schedule. A consistent theme of the decadal surveys is the importance of "balance," which includes maintaining not only a diverse portfolio of small, medium, and large missions, but also a strong research grant program in addition to missions. In addition, decadal surveys may also consider budget scenarios for the next decade, as well as technology development, research, infrastructure, and workforce.

[4] https://science.nasa.gov/about-us
[5] The National Academy of Sciences was established in 1863 by an Act of Congress signed into law by President Lincoln as an independent, nongovernmental institution to advise the government. The Academies of Engineering and Medicine were established later under the charter of the National Academy of Sciences.
[6] Section 20305(a), Title 51, U.S. Code
[7] National Academy of Sciences. 1964. *Ground-based Astronomy: A Ten-Year Program.* Washington, DC: The National Academies Press. https://doi.org/10.17226/13212.
[8] Alexander, Joseph K. *Science Advice to NASA: Conflict, Consensus, Partnership, Leadership.* 2017. NASA Office of Communications, NASA History Division. Monographs in Aerospace History, No. 57. https://www.nasa.gov/connect/ebooks/science_advice_to_nasa_detail.html.
[9] Section 18384, Title 42, U.S. Code

Astrophysics

The SMD Astrophysics Division supports research investigations with grants and a high-altitude balloon project. The Astrophysics Cosmic Origins program studies the nature and evolution of stars and galaxies and operates two flagship missions, the Hubble Space Telescope (HST) and the Stratospheric Observatory for Infrared Astronomy (SOFIA). The Physics of the Cosmos program enables study of cosmology and fundamental physics and operates the flagship Chandra X-ray Observatory. The Exoplanet Exploration program enables the search for and characterization of planets outside of our solar system and manages the development of the flagship Wide Field Infrared Survey Telescope (WFIRST) mission, which will have the same sensitivity as HST, but a new, cutting-edge suite of instruments and a field of view 100 times larger. It was the highest priority large mission of the 2010 decadal survey. Astrophysics Explorers are competitively selected small and medium class missions.

The James Webb Space Telescope (JWST), which was the highest large space project priority of the 2000 decadal survey,[10] is managed separately from the Astrophysics division. JWST will observe the universe in infrared light to study stars hidden by dust, the atmospheres of planets around other stars, and the first light from the earliest galaxies formed after the Big Bang.

The 2010 decadal survey, *New Worlds, New Horizons in Astronomy and Astrophysics*,[11] was the sixth for the astronomy and astrophysics community. The decadal survey identified three science objectives:

- Cosmic Dawn: Searching for the First Stars, Galaxies, and Black Holes
- New Worlds: Seeking Nearby, Habitable Planets
- Physics of the Universe: Understanding Scientific Principles

Astrophysics Large-Scale Priorities	
Program	*Notes from Decadal Recommendation*
1. Wide Field Infrared Survey Telescope (WFIRST)	Partnership with DOE
2. Explorer Program Augmentation	Support the selection of two Medium-Class Explorers (MIDEX), two Small Explorers (SMEX), and four Missions of Opportunity (MO)
3. Laser Interferometer Space Antenna (LISA)	Partnership with European Space Agency (ESA)
4. International X-Ray Observatory (IXO)	Partnership with ESA and Japanese Aerospace Exploration Agency (JAXA)
Astrophysics Medium-Scale Priorities	
1. New Worlds Technology Development Program	Technology development for a potential planet-imaging mission beyond 2020
2. Inflation Probe Technology Development Program	Technology development for a potential cosmic microwave background and/or inflation mission beyond 2020

[10] National Research Council. 2001. *Astronomy and Astrophysics in the New Millennium*. Washington, DC: The National Academies Press. https://doi.org/10.17226/9839.
[11] National Research Council. 2010. *New Worlds, New Horizons in Astronomy and Astrophysics*. Washington, DC: The National Academies Press. https://doi.org/10.17226/12951.

The decadal survey in astronomy and astrophysics for the 2020-2030 decade is in progress.[12]

Planetary Science

The Planetary Science Division supports research investigations through grants, curation of samples and materials collected from science missions, and management of the Planetary Data System (PDS) archive. The Division supports PI-led missions in the Discovery (small-class) and New Frontiers (medium-class) mission lines. Planetary Science is currently developing two large-scale flagship missions: the Mars 2020 Rover, which will investigate the Red Planet's past and present conditions for life and collect rock and soil samples for future return to Earth, and Europa Clipper, which will perform a detailed study of Jupiter's icy moon, Europa, which harbors a liquid ocean below its ice shell and thus a potential site for life in the Solar System. In addition, the Division is NASA's home for Planetary Defense, including observations to identify and characterize Near Earth Objects (NEOs) and testing of mitigation technology for hazardous asteroids. The Planetary Science Division manages the acquisition of radioisotope power materials, in partnership with the Department of Energy, that is needed for missions for which solar power is not feasible or sufficient.

The 2011 *Visions and Voyages for Planetary Science in the Decade 2013-2022*[13] was the second decadal survey in the field. The committee identified ten primary science questions of the next decade under three broad, crosscutting themes:

- Building new worlds—understanding solar system beginnings,
- Planetary habitats—searching for the requirements of life, and
- Workings of solar systems—revealing planetary processes through time.

The survey prioritized three large flagship space missions for the decade and also recommended one medium-scale program of two New Frontiers missions, competitively selected out of a list of candidate missions.

Planetary Science Large-Scale Priorities	
Program	*Notes from Decadal Recommendation*
1. Mars Astrobiology Explorer-Cacher (MAX-C) descope	Partnership with ESA Should be flown only if it can be conducted for a cost to NASA of no more than $2.5 billion (FY 2015 dollars)
2. Jupiter Europa Orbiter (JEO) descope	Should be flown only if changes to both the mission and the NASA planetary budget make it affordable without eliminating any other recommended missions
3. Uranus Orbiter and Probe	Should be initiated in the decade even if both MAX-C and JEO take place
Planetary Science Medium-Scale Priority	
1. New Frontiers	New Frontiers-4 candidate missions: Comet Surface Sample Return; Lunar South Pole-Aitken Basin Sample Return; Saturn Probe; Trojan Tour and Rendezvous; Venus In-Situ Explorer

[12] https://sites.nationalacademies.org/DEPS/astro2020

[13] National Research Council. 2011. *Vision and Voyages for Planetary Science in the Decade 2013-2022*. Washington, DC: The National Academies Press. https://doi.org/10.17226/13117.

	New Frontiers-5 candidate missions: All of the above not selected in New Frontiers-4, and Io Observer, Lunar Geophysical Network

Heliophysics

The Heliophysics Division supports research investigations through grants, CubeSats, and a sounding rocket program. The Living With a Star (LWS) program seeks to understand aspects of the Sun-Earth system that affect life and society and includes the study of space weather, including solar phenomena like coronal mass ejections and solar wind interactions with the Earth like geomagnetic storms, which can impact Earth's power grid, space-based technologies like communications and navigation systems, and the harmful radiation environment for humans in space. The Division's Solar Terrestrial Probe (STP) missions focus on the fundamental physical processes of the space environment; and an Explorer program for competed small and medium missions. The Heliophysics Division operates the Parker Solar Probe, which is making record-breaking close approaches to the Sun to understand its atmosphere, or corona. Heliophysics missions in development include the Interstellar Mapping Probe (IMAP), the next STP mission, and U.S. contributions to the ESA-led Solar Orbiter Collaboration mission.

The 2013 *Solar and Space Physics: A Science for a Technical Society*[14] was the second decadal survey for Heliophysics. The survey's four key science goals for the decade, "*considered of equal priority*," were:

- Determine the origins of the Sun's activity and predict the variations in the space environment.
- Determine the dynamics and coupling of Earth's magnetosphere, ionosphere, and atmosphere and their response to solar and terrestrial inputs.
- Determine the interaction of the sun with the solar system and the interstellar medium.
- Discover and characterize fundamental processes that occur both within the heliosphere and throughout the universe.

Heliophysics Decadal *Science* Priorities	
Program	*Notes from Decadal Recommendation*
1. Implement the Diversify, Realize, Integrate, Venture, Educate (DRIVE) Initiative	Includes small satellites, science centers and grant programs, and instrument development
2. Accelerate and expand the Heliophysics Explorer Program	Enable Medium Explorer and Mission of Opportunity lines resulting in an increased cadence of one launch every 2-3 years
3. Restructure Solar Terrestrial Probes as a moderate-scale, PI-led line	Implement three mid-scale missions meeting the science targets of the following reference missions (priority order): 1. Interstellar Mapping and Acceleration Probe (IMAP) 2. Dynamical Neutral Atmosphere-Ionosphere Coupling (DYNAMIC) 3. Magnetosphere Energetics, Dynamics, and Ionospheric Coupling Investigation (MEDICI)

[14] National Research Council. 2013. Solar and Space Physics: A Science for a Technological Society. Washington, DC: The National Academies Press. https://doi.org/10.17226/13060.

4. Implement a large Living with a Star (LWS) Geospace Dynamics Constellation (GDC)-like mission	

The top priority of the Heliophysics decadal survey—after maintaining the current program—is the DRIVE initiative, a "*new, integrated, multiagency initiative…that will develop more effectively the many experimental and theoretical assets at NASA, NSF, and other agencies."*

A mid-decade assessment of the progress implementing the decadal survey is currently underway and is expected to be released by the end of 2019.[15]

Earth Science and Applications

NASA's Earth Science Division supports research investigations; directed Earth system science missions; competitively selected, small, space-based and airborne missions; a significant division-wide data systems management effort; advanced technology development; and an applied science program. Operating Earth Science missions include Landsat (in partnership with USGS), the Global Precipitation Measurement mission, and the Soil Moisture Active and Passive Mission. The Division is currently developing the Landsat 9 satellite, which will continue the program's critical role in monitoring global land surface for natural and human-induced change, and the Surface Water and Ocean Topography Mission, which will make the first-ever global survey of Earth's surface water. The Division's Applied Sciences program uses Earth Science data to develop decision-making tools that serve multiple public and private sector users. Examples of applications include wildfire detection data and predictions for use by the U.S. Forest Service and the use of soil moisture data by the U.S. Department of Agriculture.

The 2018 *Thriving On Our Changing Planet: A Decadal Strategy for Earth Observation in Space*[16] was the second decadal survey for Earth science. The survey identified 35 key science and applications questions for the next decade spanning the following six areas:

- Coupling of the water and energy cycles
- Ecosystem change
- Extending and improving weather and air quality forecasts
- Reducing climate uncertainty and informing societal response
- Sea-level rise
- Surface dynamics, geological hazards, and disasters

The 2018 Earth Science decadal survey differs from other surveys in that it "*puts forth a set of priority measurements rather than prescribing specific mission implementations…this approach allows the program implementation to evolve throughout the course of the decade in order to take advantage of new ideas such as constellations of small spacecraft, advances in sensor technology, and better computational techniques."*[17] The survey paired a ranked list of distinct

[15] http://sites.nationalacademies.org/SSB/CurrentProjects/SSB_174910
[16] National Academies of Sciences, Engineering, and Medicine. 2018. *Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space*. Washington, DC: The National Academies Press. https://doi.org/10.17226/24938.
[17] https://www.nap.edu/resource/24938/RH-esas.pdf

program elements with a list of "targeted observables," or priority observations. Ahead of new priorities, the Earth Science decadal survey prioritized completion of the program of record.

Earth Science Decadal Priorities	
Program	*Notes*
2. Designated Observables	A program element for cost-capped, competed or directed, medium- and large-size missions to address observables essential to the overall program: aerosols; clouds, convection, and precipitation; mass change; surface biology and geology; and surface deformation and change.
3. Earth System Explorer	A *new* program element for competitive, cost-capped medium-size instruments and missions targeting: Greenhouse gases, Ice elevation, Ocean surface winds and currents, ozone and trace gases, snow depth and snow water equivalent; and terrestrial ecosystem structure.
4. Incubation	A *new* program element focused on investment for capabilities for priority observations: atmospheric winds, planetary boundary layer, and surface topography and vegetation, with an innovation fund to respond to emerging needs.
5. Earth Venture	Add *new* "Venture-continuity" component to existing Earth Venture program element.

NASA Science Mission Cost and Schedule Performance

The Government Accountability Office (GAO) found in its 2018 agency-wide assessment of NASA's "major projects"—those in development, with projected lifecycle costs of at least $250 million—[18] that the cost and schedule performance of NASA's "*portfolio of major projects continues to deteriorate,*" largely due to challenges with JWST's integration and testing and production challenges with the human exploration program's Space Launch System.

Science and Exploration

NASA introduced in its FY 2019 budget proposal a Lunar Discovery and Exploration budget line within the SMD Planetary Science Division. Included in the budget line is a new program, Commercial Lunar Payload Services (CLPS). Through CLPS, NASA is procuring a service as a means to deliver science, technology, and human exploration payloads to the lunar surface, starting with landers at a cadence of 1-2 launches each year. The first CLPS provider selections were announced last month.[19] Three commercial landing service providers will deliver NASA-provided payloads to the lunar surface by July 2021.

[18] GAO-19-262SP. 2019. "NASA: Assessment of Major Projects." https://www.gao.gov/products/GAO-19-262SP
[19] https://www.nasa.gov/press-release/nasa-selects-first-commercial-moon-landing-services-for-artemis-program